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# The features of gas component in spiral galaxies of the Virgo cluster


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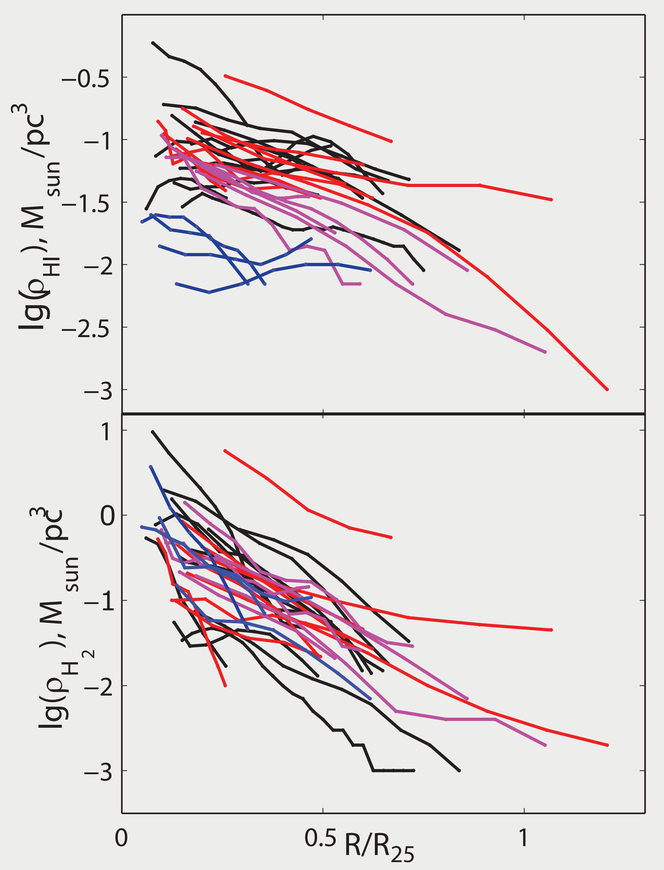
Since the star formation in galaxies is determined by the amount of molecular hydrogen, and the formation of molecules is associated with gas pressure, it is important to analyze the radial dependence of the molecular gas density, as well as to investigate the fraction of molecular gas $\eta = \Sigma_{H2} / \Sigma_{HI}$ depending on the gas pressure P. The galaxies inside and outside of clusters are compared in order to study the influence of the environment on star formation. The calculation method consists of constructing a self-consistent model of an axisymmetric disk with finite thickness in a gravitational field of dark halo taking into account a self-gravitation of gas and stars. Calculations for 12 isolated galaxies and 19 cluster galaxies have demonstrated that these galaxies can be roughly divided into several groups, which differ by the dependence of molecular gas fraction on the midplane gas pressure. The probable reason of such differences is the blowing out of atomic gas from the disc periphery in some fraction of galaxies during their passage through the central region of a cluster while keeping the molecular gas untouched, although this explanation cannot be complete.


Starformation is the fundamental process in galaxies that defines their evolution track. Despite of this a key point such as molecular cloud formation from warm atomic gas hasn't been studied sufficiently good. Many questions remained concerning both the factors that affects the transition HI - $H_2$ and physical properties of star forming molecular medium.

**One of the ways the invisible medium may be investigated is the analysis of its observational properties in different environment. The aim of this work is to compare hydrogen gas distribution in the well studied nearby galaxies and in the members of Virgo cluster.**

| | NGC | Messier | D Mpc | $D_{M\,87}$ deg | $R_{25}$ arcmin | type | IA deg | $V_r$ km/s | $H_{def}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4254 | 99 | 16.1 | 3.6 | 2.69 | 5.2 | 29 | 2410 | -0.10 |
| 2 | 4298 | | 16.1 | 3.2 | 1.48 | 5.2 | 59 | 1140 | 0.41 |
| 3 | 4302 | | 16.1 | 3.1 | 2.45 | 5.4 | 90 | 1118 | 0.39 |
| 4 | 4303 | 61 | 16.1 | 8.2 | 3.46 | 4.0 | 19 | 1570 | |
| 5 | 4321 | 100 | 16.1 | 3.9 | 3.01 | 4.1 | 38 | 1579 | 0.35 |
| 6 | 4402 | | 16.1 | 1.4 | 1.77 | 3.2 | 80 | 119 | 0.74 |
| 7 | 4414 | | 19.0 | | 2.25 | 5.2 | 55 | 716 | |
| 8 | 4419 | | 16.1 | 2.8 | 1.95 | 1.1 | 82 | -254 | 1.37 |
| 9 | 4501 | 88 | 16.1 | 2.1 | 3.38 | 3.4 | 60 | 2280 | 0.58 |
| 10 | 4535 | | 16.1 | 4.3 | 3.46 | 5.0 | 41 | 1958 | 0.41 |
| 11 | 4536 | | 16.1 | 10.2 | 3.54 | 4.3 | 59 | 1807 | 0.16 |
| 12 | 4548 | 91 | 16.1 | 2.4 | 2.63 | 3.1 | 35 | 486 | 0.82 |
| 13 | 4567 | | 16.1 | 1.8 | 1.38 | 4.0 | 43 | 2265 | 0.13 |
| 14 | 4568 | | 16.1 | 1.8 | 1.19 | 4.1 | 65 | 2255 | 0.38 |
| 15 | 4569 | 90 | 16.1 | 1.7 | 4.56 | 2.4 | 69 | -233 | 1.47 |
| 16 | 4579 | 58 | 16.1 | 1.8 | 2.51 | 2.8 | 39 | 1518 | 0.95 |
| 17 | 4647 | | 16.1 | 3.2 | 1.41 | 5.2 | 34 | 1415 | |
| 18 | 4654 | | 16.1 | 3.3 | 2.51 | 5.9 | 58 | 1034 | 0.12 |
| 19 | 4689 | | 16.1 | 4.3 | 2.29 | 4.7 | 39 | 1613 | 0.68 |

Basic characteristics of the Virgo galaxies are given in the table. Columns (5) list angular distance to M87 in degree, (9) - gives the radial velocity in km/s and (10) - HI deficiency. Color indicates the galaxies with different properties of the gas component.




Radial variations of the volume densities of atomic and molecular components in the galaxies of our sample. The Galactocentric distances are in fractions of the photometric radii $R_{25}$.

There's a lot of discussions about **the dependence of the relative molecular gas fraction on the turbulent gas pressure**. The pressure P is assumed to play a dominant role in the atomic-to-molecular gas phase transition whereas the role of UV is not so clear. The question arises: what is the best way to calculate correctly the value of P?

To calculate the pressure in galactic disks, the hydrostatic equilibrium and Poisson equations are commonly used and a number of simplifying assumptions are made. For an infinite disk with a vertical gas scale height much smaller than that for the stellar disk, when the contribution from the spheroidal components to the vertical potential gradient is ignored, the pressure of gas can be expressed by the formula:

$$P = 0.84 (G\Sigma_{star})^{0.5} \Sigma_{gas} \frac{v_{gas}}{h_{star}^{0.5}}$$

**But in this case the turbulent pressure is a function of only the stellar and gas surface densities which is a strong simplification. Moreover, the relationship loses the physical meaning at high surface densities $H_2$!**

In this study, we estimate the equilibrium turbulent pressure of the ISM that corresponds to the azimutally averaged gas density in the galactic plane at a given R. To calculate the thicknesses of three components of a disk (stars, HI, and $H_2$) in a general gravitational potential, we used the same method as that applied by Narayan and Jog [1].

$$\frac{d^2\rho_i}{dz^2} = \frac{\rho_i}{\langle (v_z)_i^2 \rangle} \left[ -4\pi G \sum_{i=1}^{3} \rho_i - \frac{\partial^2 \phi_d}{\partial z^2} \right] + \frac{1}{\rho_i} \left( \frac{d\rho_i}{dz} \right)^2$$

$$\rho_i = (\rho_0)_i \text{ and } \frac{d\rho_i}{dz} = 0$$

**We take into account both a self-gravity of the individual components and the gravitational influence of the halo, which can be significant in the outer disk regions.**

We use the data taken from the literature for atomic gas, CO, rotation curves and stellar velocity dispersion profiles by assuming a marginal gravitational stability of a disk. Strictly speaking, that gives an upper limit for the gas density.

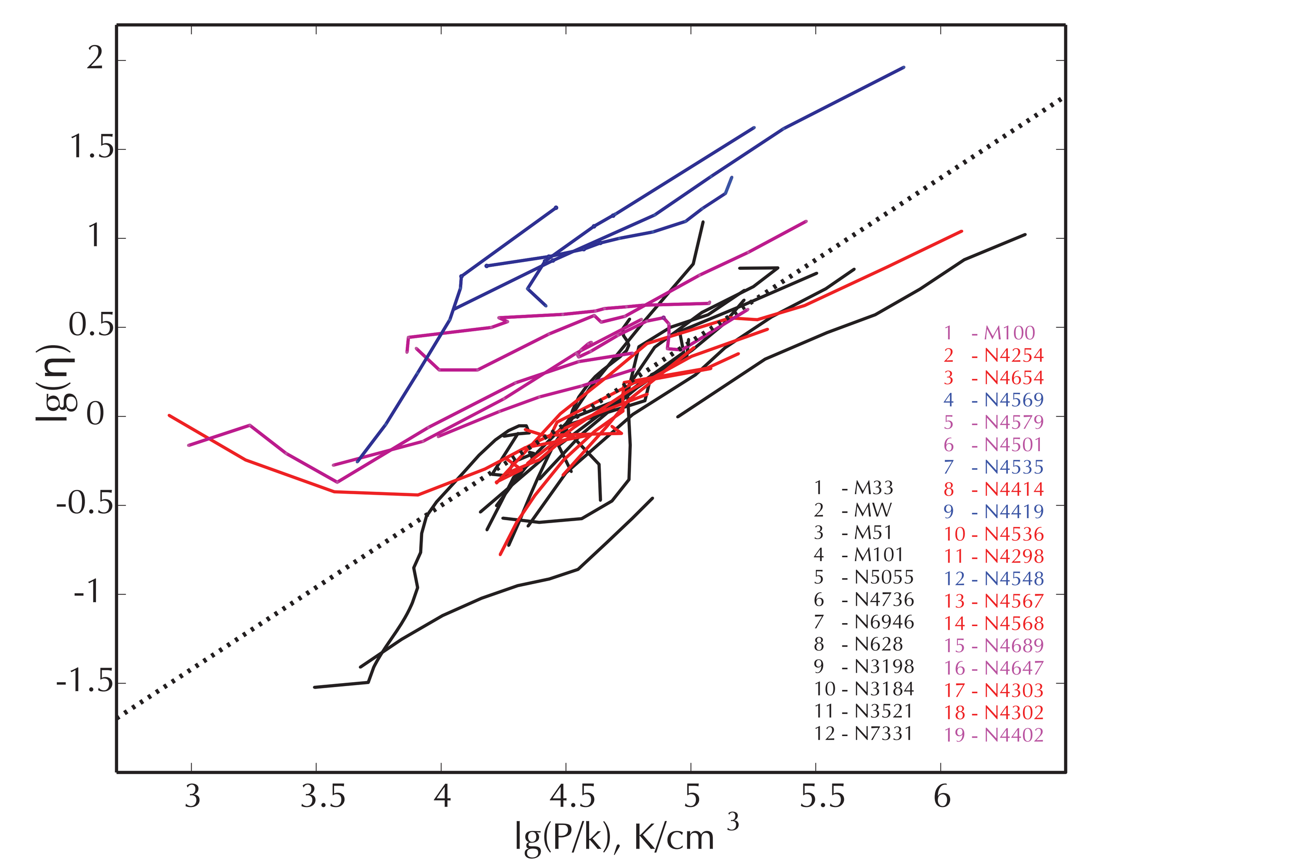



Figure above shows the dependence of the observed ratio $\eta = \Sigma_{H2} / \Sigma_{HI}$ on the estimated midplane gas pressure P. In this figure the black lines mark the field galaxies, the expected dependence for galaxies taken from [2] is marked by dotted line. It is clearly noticeable that the Virgo cluster galaxies (colour lines) have a considerable scatter. **And none of the field galaxies deviates so strong from the dotted line.**

A high fraction of molecular gas in the Virgo spirals may caausd by the next reasons:

**1. The unknown factor affecting at all radii promotes the transition HI - $H_2$.** In this case the volume density of molecular gas would be above average and/or an intensification of starformation would be observed. However $H_2$ is distributed as usual and at the same time a suppression in $H_\alpha$ and UV flux is most significant for galaxies which reveals abnormally high fraction of $H_2$.

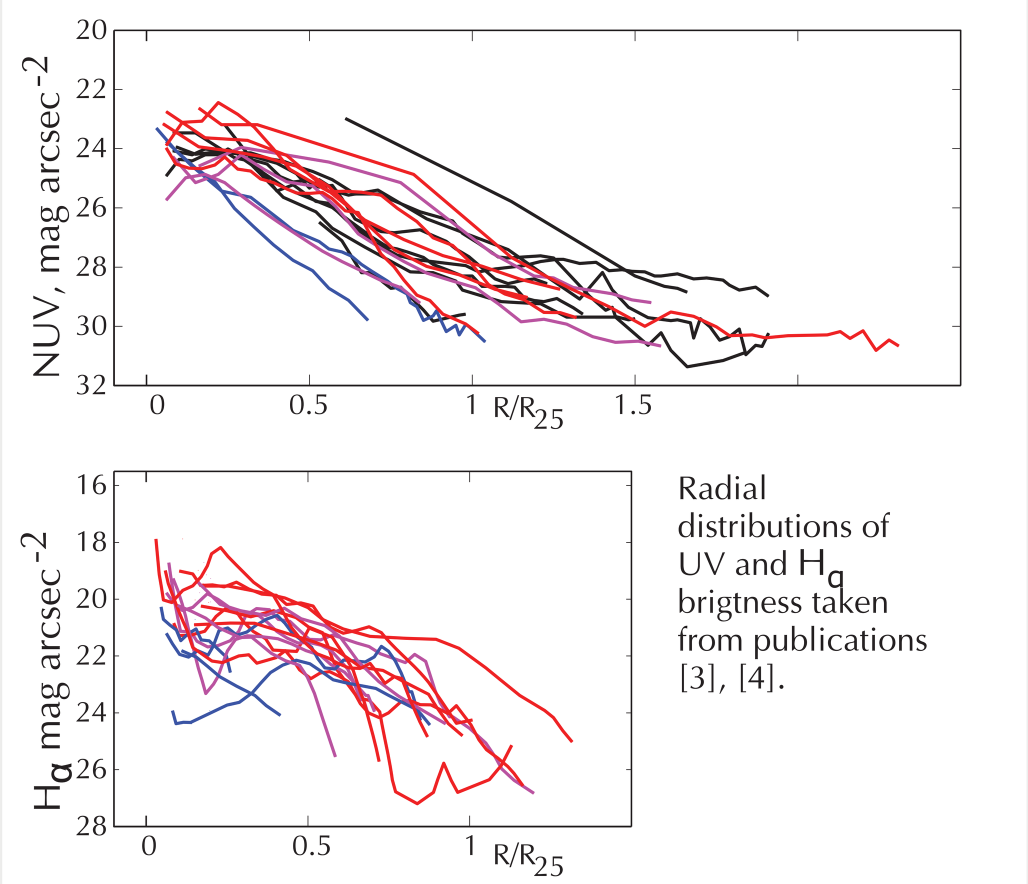
**2. Different ways of evolution of atomic and molecular gas, caused, for example, by the HI stripping.** It can account for a strong gas deficiency only at the galaxy outer regions. ICM pressure cannot perturb gas in the central parts of galaxies, so the normal fraction of molecular gas may be expected there.

To check it we divided the sample of 19 cluster galaxies into three groups, marked as red, purple and blue below.

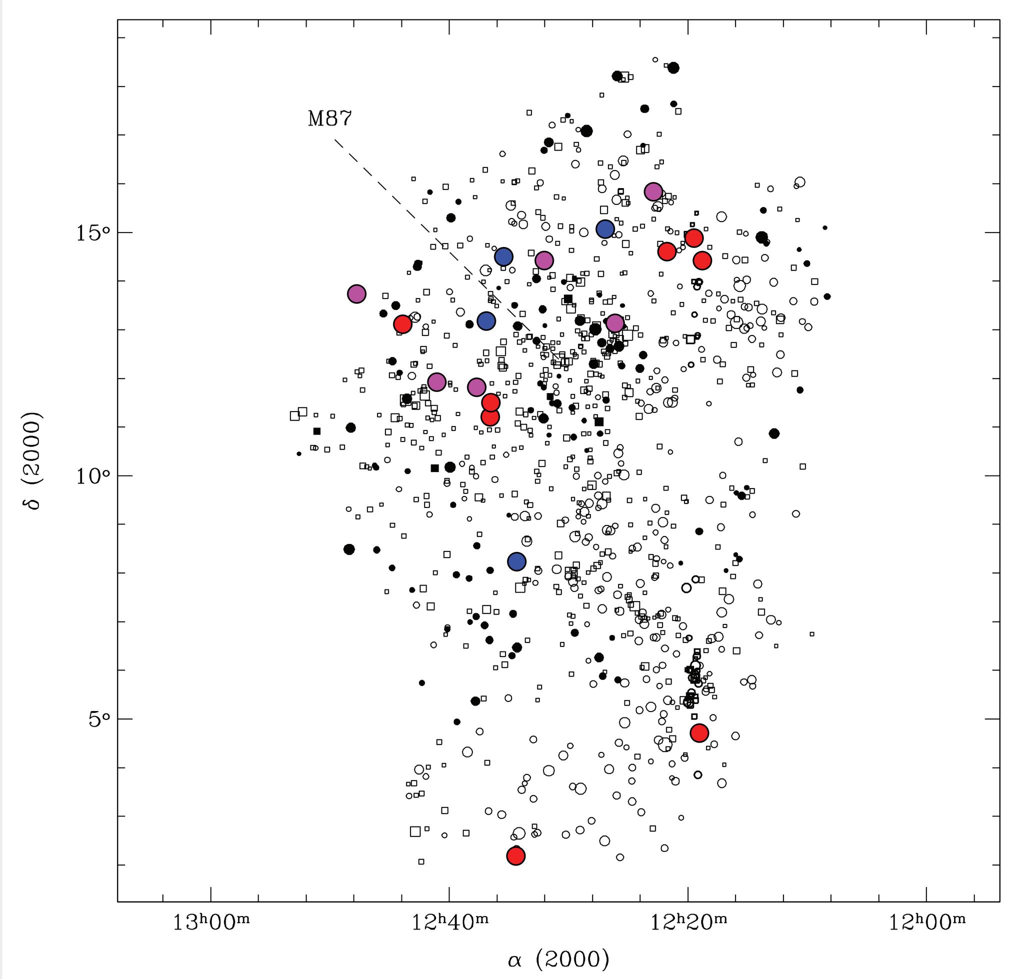
"Red" galaxies lie on a diagram indistinguishable from the field galaxies, except their peripheric regions where it can be influenced by ICM pressure.

The central regions of "purple" galaxies are practically normal, but as one moves to the edge of the galaxy η decreases slower than expected.

"Blue" galaxies lie higher an the curve from the expected dependency at all radii. We cannot explain it by the influence of the environment only. Moreover using the distribution of galaxies on the sky plane and the radial velocity distribution relative to M87 we cannot say definitely what is the reason for these galaxies to have the most stripped atomic hydrogen.




Radial distributions of UV and $H_\alpha$ brigtness taken from publications [3], [4].




Distribution map of galaxies in our sample in the field of the Virgo cluster.

The most probable is the the independent evolution of the HI and $H_2$ gas components after molecular clouds formed. Some galaxies of the sample probably already passed near the center of the cluster and have lost some of their gas there. The fact that the observed η is high means that the gas pressure in these galaxies was much higher than now when molecular gas was formed. Molecular gas manged to survive even after a bulk of HI was expelled from a disc and the pressure decreased. It may take place if the time of life of molecular clouds is higher than usually expected.


[1] Narayan C.A., Jog C.J., Astron. Astrophys. 394, 89, 2002;
[2] Blitz L., Rosolowsky E., Astrophys. J. 650, 933, 2006;
[3] Koopmann, R. A., et al. The Astroph. J. Suppl. Ser. 135, 125, 2001;
[4] Gil de Paz, A. et al. The Astroph. J. Suppl. Ser., 173, 255, 2007.